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Technical Report 863

Criterion Development and Project A Validities for the DX164 TOW2 Simulator

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This project validated Project A tests for TOW gunnery performance, provided algorithms for constructing Measures of Effectiveness (MOEs), and suggested an integrative approach (that considers both training and human ability) to identify critical human performance aspects of a weapon system. Fifty-one soldiers from the MOS 11H with varying degrees of TOW2 gunnery experience were tested with Project A reaction time, psychomotor, and spatial tests. Results indicated that these tests correlated with target acquisition times (when there is a hit) and with the probability of hitting a target during a Testing Effectiveness Evaluation (TEE) of the DX164 TOW2 simulator. The Project A Orientation Test (measuring mental rotation) and the One-handed Psychomotor Tracking Test correlated with hit probability at both pretraining and post-training performance sessions, most notably when soldiers wore fully protective gear (MOPP IV) for a nuclear, biological, and chemical conflict.

MOEs were constructed for each firing point by combining the hit probability and acquisition time measures based on the O'Keefe and Guerrier (1988) model for a MOE.
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Algorithms were employed to construct composite MOEs to obtain a criterion measure of performance across all firing points. The Orientation Test maintained its prediction of pretraining and post-training performance for algorithms that incorporated the empirical relationships among the firing points.

Discussion of TOW gunnery performance is based on an integrative approach that considers TOW gunnery stimulus testing conditions, the likelihood of encountering those conditions on a battlefield, practice effects, and ability measurement. Results suggest that Project A tests be used to select MOS 11H TOW gunners and the integrative approach presented be included in other research efforts, such as those being conducted under the MANPRINT initiative.

Technical Report 863

Criterion Development and Project A Validities for the DX164 TOW2 Simulator

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FOREWORD

During recent years, the ability of Project A tests to predict performance across different MOS has gained recognition throughout the Army. The present project determined the extent that these tests predict success of a DX164 simulated firing of a TOW 2 missile - a task requiring that the soldier quickly acquire the target, fire a simulated missile and continuously track the target as the missile approaches the target. Project A tests measuring spatial and psychomotor abilities - abilities not currently included in the Armed Services Vocational Aptitude Battery (ASVAB) - were prominent predictors of DX164 performance, even after soldiers underwent an extensive warm-up session on the DX164.

This project required interlab cooperation and coordination between ARI's Manpower and Personnel Research Laboratory and its Systems Research Laboratory. The original research was designed to be a Testing Effectiveness Evaluation Project of the DX164 TOW 2 simulator. The validation of the Project A tests was subsequently included, apparently, without interfering with the research design of the original project. Both research efforts benefited by this cooperation. The enclosed data analysis and interpretation has implications for MANPRINT efforts that integrate human ability with weapon systems development and for Project A efforts that seek to validate these tests in a variety of Army MOS.

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CRITERION DEVELOPMENT AND PROJECT A VALIDITIES FOR THE DX164 TOW2 SIMULATOR

EXECUTIVE SUMMARY

Requirement:

To determine the validity of Project A tests for predicting DX164 simulation of TOW2 gunnery performance in a sample of TOW gunners with varying degrees of TOW gunnery experience.

Procedure:

To "piggy back" onto a Testing Effectiveness Evaluation (TEE) project of the DX164 simulator conducted under the supervision of the Army Research Institute for the Behavioral and Social Sciences Systems Research Laboratory. During the course of the TEE project, test the participating soldiers with the Project A tests.

Findings:

Project A tests predicted DX164 performance both before and after the soldiers underwent an intervening training session designed to improve soldier performance on the DX164. The Project A Orientation Test (measuring mental rotation) and the one-handed psychomotor tracking test predicted performance at both the pretraining and post-training performance sessions. This was most notable in situations requiring the soldiers to wear fully protective garments for nuclear, biological, and chemical conflict. Other Project A tests predicted performance at either pretraining or post-training performance sessions. Models of psychomotor performance that incorporated predicted relationships between abilities and psychomotor performance at different stages of practice helped explain the observed ability by practice interaction effects.

Algorithms were suggested to construct composite criteria of DX164 soldier performance when (a) incorporating soldier performance across different stimulus conditions, and (b) considering the likelihood that the soldiers encounter those conditions in a real battlefield. Project A tests predicted performance of these criteria as well, but the validities, as expected, were affected by the algorithms employed and the likelihood weights assigned to the stimulus conditions.

Utilization of Findings:

The data suggest that Project A tests--notably certain spatial and psychomotor tests--be used to classify soldiers for the MOS 11H TOW gunnery task. The results suggest that efforts such as MANPRINT consider the interaction of

ability, training, stimulus conditions of system deployment, and likelihood of encountering those stimulus conditions when matching human abilities to planned systems.

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LIST OF TABLES

CRITERION DEVELOPMENT AND PROJECT A VALIDITIES FOR THE DX164 TOW2 SIMULATOR

INTRODUCTION

The Army's Project A has been developing a new set of tests that predict job performance as part of its larger effort to evaluate and augment the Army's selection and classification system. The Army's and the other services' current selection and classification battery -the Armed Services Vocational Aptitude Battery (ASVAB) - tests for Verbal, Quantitative, Technical Trade and Speed Factors. These factors may be described as statistically determined homogenous groupings of aptitudes or skills. The Project A measures were designed to test for logically or theoretically based areas (i.e., constructs) not measured by the ASVAB. These Project A constructs are represented by Psychomotor, Temperament and Interest Factors, with a Cognitive Factor, currently measured by ASVAB, expanded to include different types of spatial tests (Peterson, 1985).

The present paper looks at the extent that Project A Cognitive and Psychomotor measures predict TOW2 gunnery performance. Previous work showed that these Project A tests predict MOS 11H Advanced Individual Training (AIT) performance, which includes the qualification score on the M-70 simulator of the TOW2 launcher. The present paper widens the research focus of Grafton, et al., in at least four ways.

First, the soldiers studied in the present report have a wide range of TOW2 experience. Second, the simulator used was the DX164 rather than the M-70 simulator. Third, and perhaps most important, the present effort looked at target acquisition - a critical behavior that had been identified as important for TOW2 gunnery, but is not evaluated during AIT (Czarnolewski, 1987b; Smillie & Chitwood, 1986). Finally, the present research determines whether the Project A tests that predict DX164 performance during a warm-up session prior to a training session can still correlate with DX164 performance after training.

The primary research questions may be summarized as follows: Among a group of TOW gunners with varying TOW gun (on-the-job) experience,

1. Do Project A cognitive and psychomotor tests predict target acquisition in a TOW2 simulator?

2. Do these Project A tests relate to individual differences in target acquisition before target acquisition training?

3. Do Project A tests maintain their test validities by predicting target acquisition behavior <u>after</u> the soldiers undergo training?

During the course of this project, issues surrounding the operationalization of Measures of Effectiveness (MOEs) of TOW gunnery performance were raised. This report identifies the issues raised, most notably, identification and combination of qualitatively different testing conditions, and the effect that a particular combination algorithm for the testing conditions has on the computation of an MOE for overall TOW gunnery performance. Another issue was determining the effect that weighting a stimulus condition in terms of the likelihood that it will be encountered on the battlefield has on the computation of an MOE.

This project was a "piggy back" onto the ARI Systems Research Laboratory's (SRL) Testing Effectiveness Evaluation of the DX164 simulator (O'Keefe & Guerrier, 1988). The present paper will briefly describe that effort where appropriate (eg., Methods Section), but will not detail the research issues of that effort. The reader is referred to O'Keefe & Guerrier's work for further detail on that research effort.

Method

Subjects

Eighty-five (85) soldiers from the 9th Infantry Division (Motorized) at Fort Lewis, Washington, participated in the validation of the Project A spatial, psychomotor and reaction time tests against TOW2 gunnery performance on the DX164 TOW2 simulator. Procedural problems resulted in only 51 soldiers completing a sufficient number of trials for the criterion data that were the subject of the present report's analyses. The soldiers had varying degrees of experience with firing a real TOW2 missile and with practice on the DX164 (O'Keefe & Guerrier, 1988). They had above average GT scores, having a mean GT of 105.2 and a standard deviation of 10.9 (n=51).

Apparatus

DX164 Simulator -- The DX164 is a training device for the TOW2 missile (O'Keefe & Guerrier, 1988). It trains gunnery and tracking skills and is designed to fire simulated TOW2 missiles against real or simulated targets. It provides feedback on acquisition time (i.e., the time between a target's appearance and the soldier's firing a simulated missile), hits versus misses of the target, and other dependent measures. It is used by the Anti-Armor Theater (AAT) at Fort Lewis, for TOW2 training (SFC Guillen, Personal Communication, October, 1987).

Project A Tests -- The Project A predictor battery is designed to be an expansion of the number of constructs that may help select and classify Army recruits into different MOS (Peterson, 1985). The Project A cognitive (i.e., spatial and reaction time) and psychomotor tests were hypothesized to correlate with DX164 performance. A brief description of each test follows. The reader is referred to Peterson (1987) for further description of the tests.

The psychomotor and reaction time tests were administered either via a Sequa or Compaq microcomputer. A special response pedestal was attached to the microcomputer for test administration (see Figure 1 for depiction of pedestal). The pedestal is approximately 21 inches long and 10 inches wide. Included are two joy sticks (to allow subjects to use their preferred hand for two psychomotor tasks), "HORIZONTAL" AND "VERTICAL" controls (for another Figure 1 psychomotor task), a dial to enter demographic data, various response

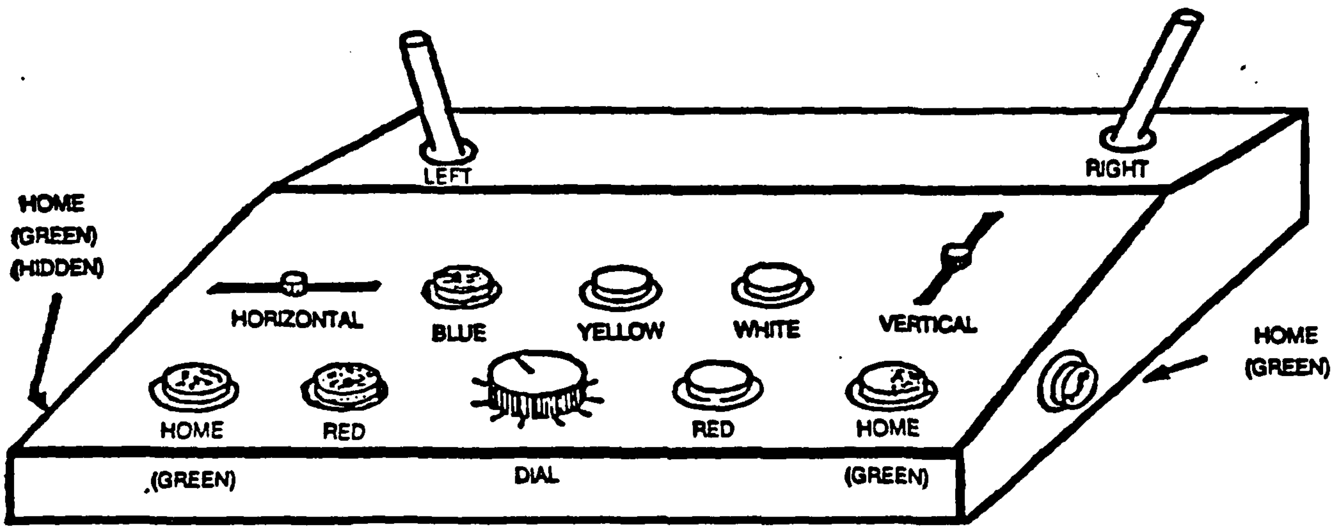

Figure 1. Response pedestal for computerized tests.

buttons, and "Home" buttons (whose function will be described shortly) (Peterson, 1987).

The reaction time (RT) tests are Simple RT, Choice RT, Short-Term Memory, Target Identity, and Perceptual Speed and Accuracy. For Simple RT, the subject presses a button when presented with a stimulus, while for Choice RT, the subject presses one button for one stimulus and another button for another stimulus. In the Short-term Memory (or Sternberg) task the subject determines whether a stimulus was present or absent in a previous array, while for the Perceptual Speed and Accuracy task, the subject decides if two stimulus arrays that are simultaneously presented with each other, completely match. In the Target Identity task, the subject matches a Military vehicle or aircraft target to one of three possible targets. The soldier presses the Home Button before the stimulus is presented on the screen. He/she then releases one, or, if they wish, both of the Home Buttons to press the appropriate response button. This procedure is intended to insure that all soldiers have the same starting positions at stimulus onset.

To obtain information on the time it takes to release a button and the time it takes to press a button, the reaction time data are separated into Decision and Movement Times. Decision Time represents the interval between the onset of the stimulus to which the subject responds and the time the subject initiates the response (i.e., the time between stimulus presentation and the soldier's releasing the "Home" button). Movement Time is the time from response initiation to response completion (i.e., time between release of the "Home" button and the press of the response button that is associated with the soldier's decision).

Another timed test is the Number Memory test in which subjects continually perform numerical operations on a sequentially presented set of numbers for each test item. Its dependent measures are percent correct, mean of initial input time, mean of the pooled operations time, and mean of the final response time. These measures capture, in order, accuracy, mean time of the first operation of the sequence, mean of the mean time for each operation (i.e., multiplication, division, addition, and subtraction) regardless of item, and mean of elapsed time across items.

The spatial tests are Paper-and-Pencil tests. They include the Assembling Objects, Map, Object Rotation, Mazes, Orientation and Spatial Reasoning tests. The Assembling Objects Test has subjects decide how an object looks when parts are put back together and how a set of objects looks when they are re-aligned. The Map Test presents the subject with the relative direction (e.g. northwest) of two of four landmarks and then has the subjects decide the direction of travel from one of the four landmarks to one of the three other landmarks. The Object Rotation Test has subjects decide whether two figures that are rotated with regard to each other match or are mirror images. The Maze Test has subjects decide which maze entrance has a path through the maze to one of its exits. The Orientation Test requires the subject to mentally rotate a frame around to the bottom of a scene (which is tilted on most items) and decide what the orientation of a feature in the frame would be after the frame's rotation. The Spatial Reasoning Test requires the subject to identify a pattern in a series of figures and decide the next figure in the series.

The last set of Project A computerized predictors are the psychomotor tests of One-handed Tracking, Two-handed Tracking and Target Shoot Tests. Another dynamic testing situation is the Cannon Shoot Task. The One-handed Tracking task requires that the subject, using a joystick, rendezvous with and remain on top of a target moving along a marked path. The stimulus is the same for the Two-handed Tracking task, but the subject follows the target by moving a horizontal slide and a vertical slide. The dependent measure for these tests captures the deviation off track. The Target Shoot task requires the subject to use a joystick to rendezvous with a target that is unpredictably changing directions, and then press a button to fire at the target when the subject is on top of the target. Its dependent measures are (a) elapsed time from trial onset till time the button to fire at the target is pressed, and (b) distance away from the target when the button is pressed. The Cannon Shoot task requires the subject to rendezvous with the target by firing a shell from a stationary position. Its dependent measure captures distance from the target as the shell either hits the target (i.e., zero distance) or crosses the trajectory of the target.

Procedure

Design. Figure 2 outlines the design of this project. Again, the primary research project was a Testing Effectiveness Evaluation of the DX164 and the evaluation of three different training techniques (represented by X_1, X_2, X_3 in the diagram). The primary project may be described as a 3 (Training Method) X 3 (Simulus Condition) X 2 (Testing Session) repeated measures ANOVA, with Training being a grouping factor and Stimulus Condition and Practice representing repeated measures.

The notation in Figure 2 is consistent with Campbell and Stanley (1966). In Campbell and Stanley different treatments are represented by an "X", with a different subscript for each treatment, and each observation of a group is represented by an "O", with each observation time given a subscript. Because Campbell and Stanley call a pre-training session a pre-test, these two terms will be used interchangeably. The terms post-training and post-test will be used interchangeably, as well.

Testing the soldiers with the Project A tests occurred after the training sessions to ensure no transfer from the Project A tests (eg., psychomotor tests which tested for tracking skill) with DX164 warmup performance at pretest or with learning during training. Approximately half of the soldiers were tested with the Project A tests prior to DX164 post-training and the rest were tested after the post-training to counter-balance any effect on post-test performance.

Each firing point represented a qualitatively different stimulus condition (Figure 2). In Firing Point 1, all the soldiers wore all the gear required for a nuclear, biological, chemical (NBC) conflict. Firing Point 2

TEST DESIGN

	Pre-Test		Post-Test
FP1 FP2 FP3	O_1	X_1	O_2
	O_1	X_2	O_2
	O_1	X_3	O_2
		Project A Testing	Project A Testing

Note:

FP1 - Firing Point 1 - Mounted Vehicle - MOPP IV (NBC)

FP2 - Firing Point 2 - Ground Mount - No MOPP

FP3 - Firing Point 3 - Mounted Vehicle - No MOPP

Figure 2. Fort Lewis Design

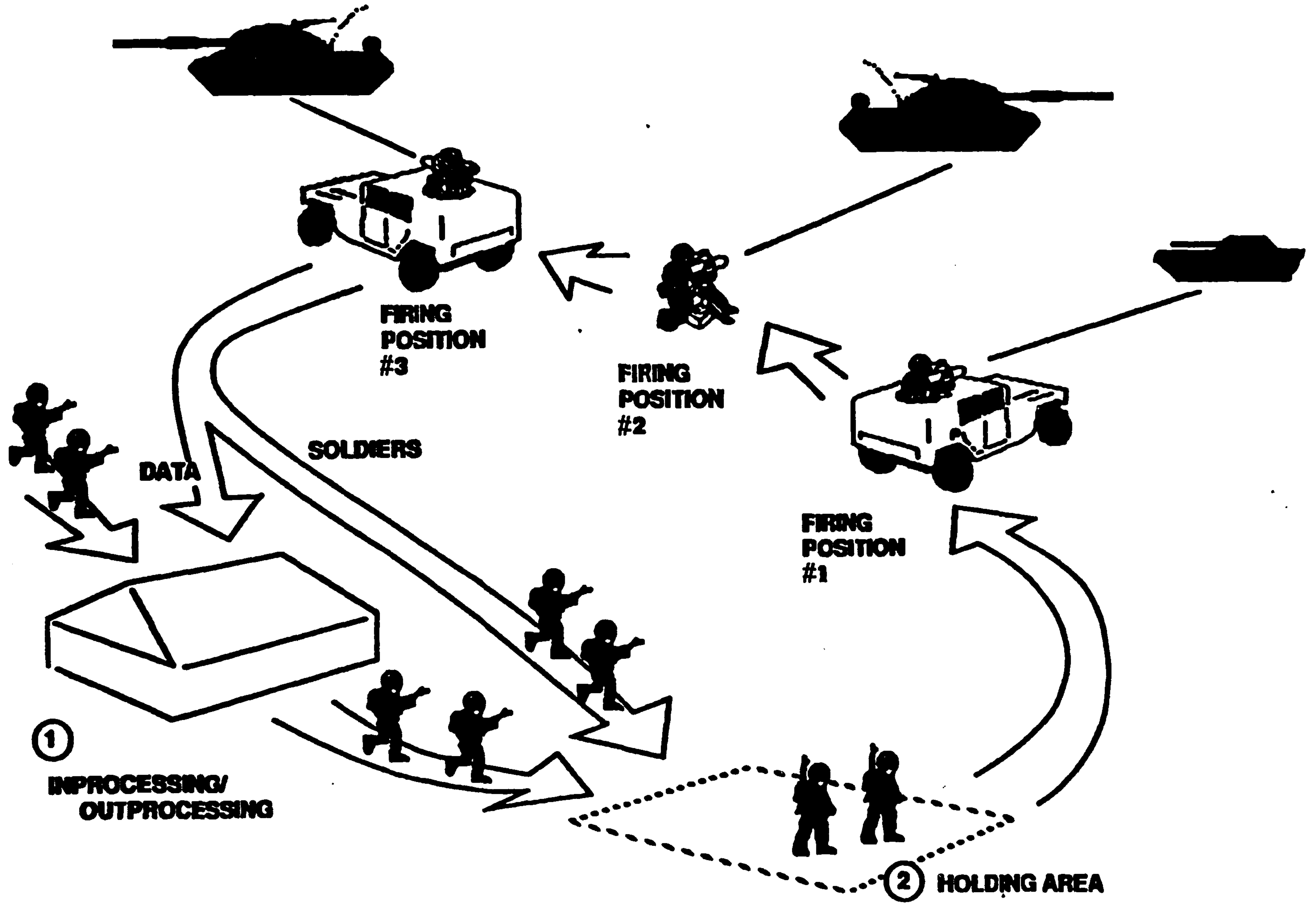

FIGURE 3. Illustration of Pre-Test/Post-Test Setup

did not require NBC gear and had the shortest and least occluded firing ranges. Firing Point 3 did not require NBC gear, as well, but did contain the most visual occlusion. The visual occlusion in some of the engagements required that the soldiers hold off firing the simulated missile until the target passed the interfering objects, e.g., trees, that were between the target and soldier. This firing point, thus simulated intervisibility based judgment, which is an important skill in TOW gunnery (Smillie & Chitwood, 1986). Firing Point 1 had six different engagements; Firing Point 2 seven engagements; and Firing Point 3 five different engagements. Soldiers had one simulated TOW 2 firing at each engagement. All three firing points had four engagements in which a real target was tracked. The remaining engagements within each firing point were computer generated targets, in which the soldier tracked targets on a video screen. Order of Firing Point and engagement were balanced across subjects. Further details of the stimulus conditions in each firing point may be found in O'Keefe and Guerrier (1988).

RESULTS

The Results Section contains five primary sections. The first section contains descriptive statistics for the accuracy and detection time criterion data, and for the correlations within the accuracy data and within the time data. For these and other analyses, except where noted, descriptive and correlational analyses are separately presented for pre-training and post-training performance sessions, and for each firing point within each performance session. The second primary section contains descriptive statistics for the Project A data. The third section contains correlations between the Project A measures and the DX164 accuracy and (acquisition) time measures. The fourth section shows how a Measure of Effectiveness is computed - a measure which combines both accuracy and time measures into one dependent measure. Correlations are computed between Project A measures with the MOE for each firing point. Finally, after employing different algorithms for combining the MOE of each firing point into a composite MOE, correlations are computed between the Project A measures and each composite MOE.

Criterion Data. Table 1 provides descriptive statistics of the criterion data. The firing point measures are hit probability (i.e., proportion of correct responses) and response time of correct responses (i.e., correct response time).

Post-training performance is better than pre-training performance, with proportion of hits being larger and less varied for each firing point. These effects are most apparent for Firing Point 1. At post-training, Firing Point 3 contains the most errors and Firing Point 2 the least number of errors. Firing Point 2 is the firing point with the fastest times for both pre-training and post-training testings.

Table 1

Proportion Correct and Correct Response Time Means and Standard Deviations for Pre-Training and Post-Training Testing on the DX164

	Pre-Training Testing		Post-Training Testing	
	X	S.D.	X	S.D.
Each Firing Point (FP)				
Proportion Correct				
FP1	.81	.21	.90	.13
FP2	.91	.11	.98	.07
FP3	.79	.19	.84	.16
Correct Response Times				
FP1	11.4	5.5	8.6	1.6
FP2	6.4	0.98	5.4	0.39
FP3	10.2	2.2	10.0	1.4

Intercorrelations Among Firing Points. Table 2 shows that Firing Point 3 has negative correlations with the other two firing points at post training for the proportion correct dependent measure (Table 2). Table 2 also shows only limited consistency in proportion correct between pre-training and post-training performance, with only Firing Point 2 having a significant correlation between pre-training and post-training, $r = .37$, $p < .01$. A significant correlation between pre-training and post-training response time is also found for the Firing Point 1, $r = .29$, $p < .05$.

Table 2

Proportion Correct and Response Time Intercorrelations Among Firing Points (FP) at Pre-Training and Post-Training Testing.

	Proportion Correct					
	Pre-Training			Post-Training		
	FP1	FP2	FP3	FP1	FP2	FP3
Pre-Training						
FP1						
FP2	.23	---				
FP3	.00	-.16	---			
Post-Training						
FP1	.26	.14	-.12	---		
FP2	.32*	.37**	-.06	.37*	---	
FP3	-.20	.16	-.16	-.05	-.24	---
	Correct Response Time					
Pre-Training						
FP1	---					
FP2	.17	---				
FP3	.02	.20	---			
Post Training						
FP1	.29*	.01	-.05	---		
FP2	.24	.26	-.07	-.07	---	
FP3	-.08	.02	-.08	.01	-.02	---

n = 51. *p < .05; **p < .01

Table 3

Means and Standard Deviations of the Project A Measures for the Total Sample and the Studied Sample[1] in the Fort Lewis Project

	Total Sample[2]		Studied Sample[3]	
	x	S.D.	x	S.D.
Simple Reaction Time				
Percent Correct	99	3	98	4
Decision Time Mean	283.1	34.7	279.6	34.7
Movement Time Mean	258.7	96.4	267.6	101.0
Choice Reaction Time				
Percent Correct	99	2	99	2
Decision Time Mean	394.2	80.4	390.0	59.5
Movement Time Mean	259.3	63.7	258.3	64.8
Short Term Memory				
Percent Correct	90	6	90	6
Decision Time Mean	801.1	245.9	801.2	235.4
Movement Time Mean	347.6	108.7	339.3	99.5
Perceptual Speed & Accuracy				
Percent Correct	87	9	86	9
Decision Time Mean	2254.0	615.1	2234.8	667.4
Movement Time Mean	302.4	80.2	299.8	78.5
Target Identification				
Percent Correct	92	6	92	6
Decision Time Mean	1602.1	487.3	1516.8	472.4
Movement Time Mean	325.4	85.7	331.4	90.2
Number Memory				
Percent Correct	87	10	88	11
Final Response Time	1463.3	357.0	1421.1	349.3
Pooled Operations Mean	236.2	76.9	229.8	216.6
Initial Input Time Mean	146.4	42.6	145.1	41.3
Psychomotor Tests				
Tracking				
One-Hand Tracking	2.86	.39	2.83	.40
Two-Hand Tracking	3.38	.49	3.34	.52
Cannon Shoot				
Mean Abs. Time Discrepency	432.5	80.7	430.8	84.3
Target Shoot				
Mean Time to Fire	2338.8	490.2	2314.2	524.7
Mean Log (Dist. + 1) Error	2.11	.16	2.08	.16
Spatial Tests				
Spatial Reasoning	19.8	5.4	19.9	5.8
Object Rotation	67.8	16.2	69.6	13.6
Orientation	12.9	6.2	13.2	6.2
Maze	18.5	4.4	18.6	4.4
Map	9.3	5.6	8.7	5.6
Assembling Objects	26.2	5.6	25.8	5.9
ASVAB				
GT Composite	106.1	11.6	105.2	10.9
CO Composite	109.1	11.7	108.3	11.5
AFQT	56.3	20.0	54.9	18.8

Note. Times are in msec.
[1]Studied Subjects had sufficient criterion data to compute validities.
[2]Number of cases for total sample are between 75 and 81.
[3]Number of cases for studied sample are between 44 and 49.

The data confirm the O'Keefe and Guerrier hypotheses that the firing points capture qualitatively different stimulus conditions and that practice results in improved performance for the testing conditions captured by the firing points. Of note are the negative correlations among the firing points, especially at post-training for the proportion correct dependent measure. Discussion regarding the negative correlations among the firing points, as well as the lack of consistency (i.e., low pre-training/post-training correlations for each firing point) will be found in the part of the Results Section dealing with Measures of Effectiveness and in the Discussion Section.

Descriptive Statistics of the Predictors. Table 3 presents the means and standard deviations of the Project A predictors for those soldiers containing sufficient criterion data and for the entire sample. The data appear analogous to other Project A results and provide preliminary support for the argument that norms for the Project A predictors are not affected by specific on-the-job experience as defined by MOS.

Correlations Between Project A Tests and DX164 Performance. There were three primary hypotheses that were tested. First, the Project A tests correlate with target acquisition behavior. Second, the tests predict performance prior to training. Third, the expected decrease in individual differences in criterion performance due to training would not preclude Project A tests from correlating with post-training criterion performance. The data will show that Project A tests predict criterion performance at both pre-training and post-training on the DX164.

The psychomotor and spatial tests best predict Firing Point 1 performance at both pre-training and post-training on the DX164. Table 4 presents these data. Again, Firing Point 1 required that the soldiers wear MOPPIV gear and this stimulus condition appears to elicit individual differences in performance related to the psychomotor and spatial tests. Significant predictors at pre-training included two psychomotor tests (i.e., One-hand Tracking and Target Shoot tests) and four spatial tests (i.e., Spatial Reasoning, Orientation, Map, and Assembling Objects tests). Significant psychomotor predictors at Firing Point 1 at post-training include the One-hand and Two-hand Tracking tests and the Target Shoot test. The distance (off-track) Target Shoot measure predicted accuracy performance at pre-training and the Time to Fire Target Shoot measure predicted accuracy performance at post-training. The Orientation and Maze Tests predicted performance at Firing Point 1. Other notable correlations are found for the Maze and Assembling Objects tests for post-training at Firing Point 2.

Predictors at both pre-training and post-training include the Maze and Orientation tests (see Table 4). The response time measure appears to provide incremental information for evaluating the predictive power of Maze at pre-training, as seen by its prediction of pre-training correct detection time performance while not predicting pre-training accuracy performance.

Table 4

Pretest and Post-test Correlations of Project A Spatial and Psychomotor Tests with Accuracy and Correct Time Criterion Measures

	Pretest			Post Test		
	% Correct		Correct Times	% Correct		Correct Times
	Firing Point 1	Firing Point 2	Firing Point 1	Firing Point 1	Firing Point 2	Firing Point 1
Psychomotor Tracking						
1-hand	-.28*	.00	.33*	-.34*	.00	.20
2-hand	-.17	.03	.28	-.33*	.01	.14
Cannon Shoot	-.10	-.18	.13	-.19	-.05	-.06
Target Shoot						
Time to Fire	-.06	-.08	.23	-.30*	.01	.10
Distance	-.36*	.07	.10	-.07	-.21	.23
Spatial						
Spatial Reasoning	.30*	.13	-.14	.17	.27	-.12
Object Rotation	.18	-.10	.20	.05	.01	.08
Orientation	.47***	-.09	-.31	.52***	.09	-.10
Maze	.26	.09	-.31*	.35*	.30*	.03
Map	.40**	.02	-.18	.17	.25	.06
Assemble Objects	.30*	.01	-.14	.14	.35*	-.06

*$p < .05$; **$p < .01$; ***$p < .001$

An unexpected result was a consistent inverse relationship of the Project A psychomotor and spatial tests with criterion performance at Firing Point 3, with Assembling Objects' negative correlation with DX164 accuracy being significant $r = -.29$, $p < .05$. These negative correlations, although consistent with the negative correlations of Firing Points 1 and 2 with Firing Point 3 for the proportion correct dependent measure (see Table 2) require explanation. Possible explanation(s) of these and other negative correlations with Firing Point 3 are reserved for the Discussion Section.

Table 5 shows the significant correlations of the Project A reaction time tests with performance at pre-training and post-training. The Number Memory Test's Final Response measure appears to be a relatively consistent predictor of performance. The Number Memory Test requires that one continually perform numerical operations on a sequentially presented set of numbers. The Final Response measure is the average of the time that it takes one to complete the numerical operations on each set of sequentially presented numbers. The Number Memory and Choice Reaction Time tests predict performance at pre-training and post-training, especially for Firing Point 2.

Table 6 presents significant correlations for Firing Point 3 pre-training response times on the DX164. These correlations are no longer significant at post-training for Firing Point 3.

Table 5

Pre-test and Post-test Correlations of Project A Reaction Time Tests with Accuracy and Correct Time Criterion Measures

	Pre-test			Post-Test		
	% Correct		Correct Times	% Correct		Correct Times
	Firing Point 1	Firing Point 2	Firing Point 1	Firing Point 1	Firing Point 2	Firing Point 1
Simple RT						
Movement Time	.07	.24	.11	-.06	-.08	.34*
Decision Time	-.13	-.36*	.31*	-.04	.00	.09
Choice RT						
% Correct	.28	.34*	.13	.22	.47***	-.04
Decision Time	-.09	-.23	.30*	-.15	.06	-.15
Short-Term Memory						
Decision Time	-.21	-.28	-.03	-.26	-.17	-.18
Number Memory						
Final Response	-.49***	-.31*	.14	-.11	-.28*	.03

*$p < .05$; **$p < .01$; ***$p < .001$

Table 6

Firing Point 3 Pretest Correlations Between Project A Tests and Correct Time Criterion Measure

	Firing Point 3 Correct Times
Assemble Objects	.33*
Short-Term Memory	
Decision Time	.39**
Perceptual Speed & Accuracy	
Decision Time	.29*
Number Memory	
Final Response Time	.33*
Mean Operation Time	.31*

*$p < .05$; **$p < .01$

Correlations Between Project A Tests and MOEs. This section combines the acquisition time and percent correct data to form the MOE composites whose descriptive statistics are presented in Table 7 and are operationalized in Table 8. It will be shown that obtaining MOEs for each firing point gives one greater flexibility for computing composites that better capture individual differences across qualitatively different stimulus conditions. Secondly, one can weight these qualitatively different stimulus conditions to reflect other differences, such as the likelihood that a soldier would encounter the stimulus conditions of a particular firing point, for example, on a real battlefield.

The top half of Table 7 contains descriptive statistics for the proportion correct and response times having a hit, which were previously presented. Descriptive statistics for a measure of effectiveness (MOE) for each firing point are in the table, as well.

The MOEs in Table 8 are primarily based on the O'Keefe and Guerrier (1988) model. This model multiplies hit probability by an inverse value of the detection times associated with a hit. Operationally, O'Keefe and Guerrier computed the proportion of hits for each firing point and then computed the mean of these three proportions to represent hit probability. The acquisition time value is the average of acquisition times for all the daytime engagements having a hit. There were two simulated night engagements which had much longer times, and the times for these engagements were excluded when computing an inverse value of the average time for a hit. O'Keefe and Guerrier computed a separate MOE for pre-training and post-training to evaluate the effect of practice on performance. Thus, the maximum number of engagements for computing the hit probability measure was 18 and for the time measure was 16 at both pre-training and post-training, and these values are used to compute one composite MOE for pre-training and one for post-training.

The top half of Table 8 presents descriptive statistics for the MOE for each firing point. That is, the proportion correct value is multiplied by the inverse of the acquisition times having a hit. This allows for operationalizing different models of MOE composites. Details regarding the MOE composites will be presented shortly. However, it should be noted that MOE Composites C, D, E and F represent different combinations of each firing points standardized MOE. This resulted in these four composites having a mean of zero, but a standard deviation not equal to 1. (Standard deviations of 1 are associated with "standardized" scores.)

Correlations Between Project A Tests with MOEs at Each Firing Point. The correlations between the Project A measures and the MOEs for each firing point reflect the Project A/proportion correct correlations for each firing point. The detailed analyses presented in Tables 8 and 9 were reserved for the MOE dependent measure because it duplicates and adds slightly to the analyses for the proportion correct dependent measure. Where proportion correct is the more sensitive dependent measure, mention of significant correlations between Project A tests and proportion correct is found in the text.

Table 7

Proportion Correct, Correct Response Time and Measures of Effectiveness (MOEs) Means and Standard Deviations for Pre-Training and Post-Training Testing on the DX164

	Pre-Training Testing		Post-Training Testing		MOE Composite
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	
I. Each Firing Point (FP)					
Proportion Correct					
FP1	.81	.21	.90	.13	
FP2	.91	.11	.98	.07	
FP3	.79	.19	.84	.16	
B. Correct Response Times					
FP1	11.4	5.5	8.6	1.6	
FP2	6.4	.98	5.4	.39	
FP3	10.2	2.2	10.0	1.4	
C. MOE					
FP1	.61	.27	.72	.20	
FP2	.76	.18	.89	.11	
FP3	.54	.26	.62	.22	
Average	.64	.14	.75	.10	B
II. MOEs Across Firing Points					
A. SRL MOE	.63	.15	.75	.10	A
B. All Three FPS					
1. Equal Weight	0.0	1.98	0.0	2.13	C
2. Unequal Weight	0.0	0.68	0.0	.73	D
C. Firing Points 1 and 2					
1. Equal Weight	0.0	1.61	0.0	1.64	E
2. Unequal Weight	0.0	.81	0.0	.83	F

n = 51

Note. SRL MOE (Systems Research Lab's MOE) is the O'Keefe & Guerrier (1988) MOE.

Table 8

Operational Definitions for Measure of Effectiveness (MOE) Composites.

Composite A: $$1/3 \times \left(\sum_{f=1}^{3} H_f \right) \times \sum_{i=1}^{16} T_i \, r$$

where) f = Firing Point Number

H = proportion hit for that Firing Point

T_i = Response Time for each engagement, $\left[\frac{66-T_i}{65}\right]$

r = 1 if hit

0 if miss

Composite B: $$1/3 \times \left(\sum_{f=1}^{3} H_f \times \sum_{f=1}^{3} T_f \, r \right)$$

See notation for Composite A

Composite B'*: same as B, but standardize $H_f \times T_f$ for each Firing Point (f) before averaging across firing points, i.e., $Z_f = (H_f \times T_f)$. This is a standardized MOE for each Firing Point

Composite C: Standardize as in B; but give Firing Point 3 a negative weight, such that $Z_1 + Z_2 - Z_3$ = MOE Composite C.

Composite D: same as C, but weight Firing Points, such that $.2Z_1 + .3Z_2 - .5Z_3$ = MOE Composite D.

Composite E: same as C; but for only Firing Points 1 and 2 $Z_1 + Z_2$ = MOE Composite E.

Composite F: same as D, but weight only Firing Points 1 and 2 $.4Z_1 + .6Z_2$ = MOE Composite F.

Note: Weights for Composites D and F were determined by an SME (see text).

Two predictors for pre-training and post-training at the firing point requiring MOPP IV gear (Firing Point 1) are the One-handed Psychomotor Tracking Test and the Orientation Test. Other spatial or psychomotor tests appearing to be significant predictors for this firing point at pre-training include the Spatial Reasoning, Map, Assembling Objects and Target Shoot Tests. The Maze Test emerges as a prominent predictor at Firing Points 1 and 2 at post-training and Assembling Objects becomes a predictor of post-training performance at Firing Point 2. The Two-Handed Tracking Test and Target Shoot's Mean-Time-to-Fire measure become predictors at post-training for Firing Point 1.

Finally, the Number Memory and Choice RT tests predicted MOE performance (Table 9) most notably at Firing Point 2 pre-training and post-training, as they predicted percent correct for these stimulus conditions (Table 5).

In summary, operationalizing MOEs for qualitatively different stimulus conditions as represented by the different firing points resulted in the confirmation of the hypothesis that the Project A tests correlate with both pretest and post-test DX164 performance (e.g., Orientation and Choice RT). Some Project A tests were more significant predictors at post-training than at pre-training (e.g., Maze and Assembling Objects tests) and other Project A tests were more dominant predictors at pre-training than at post-training (e.g. Map and Number Memory tests). There was also an unexpected pattern for Firing Point 3, with the better a spatial test score, the poorer the MOE performance. A detailed discussion of all these results is presented in the Discussion Section.

Combining Each Firing Point MOE into a Composite MOE. The composite measures at the bottom half of Table 7 are MOEs across all three firing points and across the first two firing points. The MOE composite either gives each firing point an equal weight or a unique weight. The unique weights assigned to the firing points were suggested by a subject matter expert from SRL. The weights reflect the relative frequency that the scenario captured by the firing point could be experienced by a TOW2 gunner. All measures in Table 7 are computed for both pre-training and post-training testings.

Table 10 presents the formulas for computing the MOE composites. Again, the basic idea for all the formulas is to multiply an average proportion correct measure by an average correct response time measure (O'Keefe & Guerrier, 1988). The response time measure is subtracted from a large value (ie. 66), with the result that higher numbers reflect better performance for correct response times just as higher numbers reflect better performance for proportion correct. Two examples of MOE composites are composites A and B. Composite A multiplies the average of the proportion correct for each firing point by the average of the times across all engagements, with each correct time being subtracted from a large value that is converted to a proportion. The result is a proportion (proportion hits times a proportion representing time) that varies between 0 and 1. Composite B differs by multiplying the proportion hit for a firing point by that firing point's proportion time measure. One then averages across firing points.

Table 9

Pre-test and Post-test Correlations Between Project A Psychomotor and Spatial Measures (and ASVAB Composites) with Measure of Effectiveness (MOE) Performance for Each Firing Point

	Measure of Effectiveness					
	Pre-Test			Post-Test		
	Each Firing Point 1	2	3	Each Firing Point 1	2	3
<u>Psychomotor Tests</u>						
Tracking						
One-Handed Tracking	-.29*	-.01	-.01	-.35*	-.02	.08
Two-Handed Tracking	-.16	-.03	-.04	-.33*	.00	.01
Cannon Shoot						
Mean Abs. Time Discrep.	-.11	-.18	-.01	-.08	-.07	-.18
Target Shoot						
Mean Time to Fire	-.07	-.06	.14	-.30*	-.01	-.10
Mean Log (Dist.+1) Error	-.33*	.06	-.04	-.10	-.20	-.04
<u>Spatial Tests</u>						
Spatial Reasoning	.36*	.13	-.21	.19	.28	-.15
Object Rotation	.22	-.09	.04	.07	.03	-.17
Orientation	.45**	-.08	.16	.56***	.10	-.26
Maze	.25	.09	-.01	.35*	.30*	-.10
Map	.41**	-.01	.01	.20	.26	-.13
Assembling Objects	.30*	.00	.00	.15	.35*	-.26
<u>ASVAB</u>						
GT Composite	.04	-.09	-.20	.07	.12	-.05
CO Composite	.07	-.06	-.02	.06	.03	-.16

N = 51

*$p < .05$; **$p < .01$; *** $p < .001$

Table 10

Pre-Test and Post-Test Correlations of Project A Reaction Time Measures with Measure of Effectiveness (MOE) Performance for Each Firing Point and Across Firing Points

	Measure of Effectiveness					
	Pre-Test			Post-Test		
	Each Firing Point			Each Firing Point		
	1	2	3	1	2	3
Simple Reaction Time						
Percent Correct	.02	.07	-.24	.10	-.02	.15
Decision Time Mean	-.13	-.38**	.11	-.09	-.01	-.04
Movement Time Mean	.06	.25	-.12	-.09	-.09	.16
Choice Reaction Time						
Percent Correct	.22	.33*	.19	.20	.46***	-.01
Decision Time Mean	-.15	-.25	.03	-.18	.03	.14
Movement Time Mean	-.17	.22	-.06	-.10	-.07	-.02
Short Term Memory						
Percent Correct	.04	-.24	.03	-.09	-.15	-.01
Decision Time Mean	-.19	-.28	.13	-.26	-.18	.04
Movement Time Mean	-.03	-.01	-.06	-.06	-.08	-.07
Perceptual Speed and Accuracy						
Percent Correct	.06	-.15	.06	.04	-.19	-.02
Decision Time Mean	.03	-.13	.10	-.05	-.25	.20
Movement Time Mean	-.11	.02	-.10	-.14	-.19	-.16
Target Identification						
Percent Correct	-.08	-.01	.04	-.03	-.16	.09
Decision Time Mean	-.26	-.11	.15	-.05	-.27	.24
Movement Time Mean	-.04	-.07	.01	-.06	-.09	.04
Number Memory						
Percent Correct	-.01	-.06	-.21	.11	-.21	.02
Final Response Time	-.48***	-.32*	.14	-.15	-.29*	.01
Pooled Operations Mean	-.24	-.16	.17	-.16	-.06	-.04
Init Input Time Mean	-.09	.02	.09	-.25	.10	-.06

*$p < .05$; **$p < .01$; *** $p < .001$

One again should note that the proportion of hits that are part of the MOEs are based on all the nonmissing trials. The time measure component of the MOEs excludes two of the simulated night trials that elicited much longer times. The MOE is, thus, a composite of proportion correct for all trials and a proportion time measure for all but the night trials.

Table 11 shows the intercorrelations among the MOE composites and proportion correct measures. The bottom triangle contains the correlations among the pre-training measures and the top triangle contains the correlations among the post-training measures.

There appears to be a similar pattern among the correlations at post-training as at pre-training. The correlations are extremely high between proportion correct and Composites A, B and B' and much lower with the MOE composites containing a negative weight for Firing Point 3 (i.e., Composites C and D).

Composites C and D show the lowest correlations with the other MOEs; Composite C shows a moderate correlation with Composite B ($r = .45$, $p < .001$) at pre-training and $r = .47$, $p < .001$ at post-training; and Composites C and D correlate highly with each other. Justification for the negative weights for Firing Point 3 is seen by the negative correlations between Firing Point 3 with the other two firing points and the positive correlations between Firing Points 1 and 2 (Table 12). The pattern of MOE intercorrelations appears similar to the proportion correct intercorrelations, rather than correct detection time intercorrelations as found in Table 2, thus, reflecting a much larger weight given to proportion correct than to correct detection time in the MOE model. Possible reasons for this pattern of MOE correlations will be presented in the Discussion Section.

Table 11

Intercorrelations Among Proportion Correct and Composite Measures of Effectiveness (MOEs) at Pre-Training and Post-Training

		1	2	3	4	5	6
Proportion Correct	(1)		.96	.97	.91	.18	-.09
MOE A	(2)	.98		.99	.97	.29	.02
MOE B	(3)	.98	.10		.96	.27	.00
MOE B'	(4)	.96	1.0	.99		.47	.23
MOE C	(5)	.32	.38	.37	.44		.96
MOE D	(6)	.01	.07	.06	.15	.95	

Note. Top triangle contains correlations at post-training; lower triangle contains correlations at pre-training. The r's $\geq .28$ are significant at the .05 level, and the r's $\geq .36$ are significant at the .01 level. N = 51.

Correlations of Project A Tests with MOE Composites. Tables 14 and 16 present the correlations of psychomotor and spatial tests with composite MOEs for both pre-training and post-training, respectively. The formulas for each MOE is outlined in Table 10. The MOEs, again, primarily differ in terms of their treatment of Firing Point 3 and weight assigned to each firing point in terms of the likelihood that a soldier would encounter the battlefield conditions simulated by that firing point.

As noted previously, Firing Point 3's percent correct measure has a negative correlation with percent correct in Firing Points 1 and 2, indicating that those soldiers who are better performers at Firing Points 1 and 2, tend to be poorer performers at Firing Point 3. This inconsistency leads to three possible strategies when computing a composite MOE across the three firing points.

The first approach is to ignore this apparent trend and to sum the data in a straightforward manner. Composites A and B (as well as B') do this. Two other approaches are to give a negative weight to Firing Point 3 to reflect this inverse relationship (e.g., Composites C and D) or to drop Firing Point 3 from an MOE Composite because of Firing Point 3's apparent anomaly (e.g., Composites E and F).

Assigning weights reflecting "encounter probability", to each firing point also affects the MOE composite. Composites C and E (as well as B) give each firing point a unit weight. For Composite D, Firing Point 1 is given a weight of .2; Firing Point 2 is given a weight of .3; and Firing Point 3 is given a weight of .5. Composite F gives Firing Point 1 a weight of .4 and Firing Point 2 a weight of .6; thus, making it analogous to Composite D, but without consideration of Firing Point 3.

Composite A does not have separate MOEs for each firing point; thus there is no weighting for this composite. Weighting Composite B does not provide incremental information.

Comparing the pattern of significant correlations between Project A tests and different MOE composites in Tables 8 and 9 to Tables 11 - 14 would elucidate the effect that the treatment of Firing Point 3 and the weights for "encounter probability" have on the correlations between a test and a particular MOE composite.

At pre-test, for example, the Orientation Test has positive correlations with the MOEs for Firing Points 1 and 3 and a small negative correlation with the MOE for Firing Point 2. It is important to point out that the MOE

Table 12

Intercorrelations Among Each Firing Point's (FP) MOE at Pre-Training and Post-Training

	Pre-Training Intercorrelations		
	FP1	FP2	FP3
FP1			
FP2	.30*		
FP3	-.01	-.15	
	Pre-Training Intercorrelations		
	FP1	FP2	FP3
FP1			
FP2	.35*		
FP3	-.19	-.23	

*p < .05

Table 13

Pre-test Correlations of Some Project A Reaction Time (RT) Tests with Different Measures of Effectiveness (MOE)

	Measure of Effectiveness					
	Firing Points (FP) 1, 2 and 3					
	FP3 with Positive Weight		FP3 with Negative Weight		Firing Points 1 and 2	
RT Tests	Raw Score (A)	Stand. Score (B')	Stand. Score (C)	Wt. Stand. Score (D)	Stand. Score (E)	Wt. Stand. Score (F)
Simple RT Decision Time	-.18	-.22	-.32*	-.29*	-.32*	-.35*
Choice RT % Correct	.37**	.40**	.18	.07	.34*	.35*
Short-term Mem. Decision Time	-.17	-.19	-.31*	-.28	-.30*	-.30*
Number Memory Final Response	-.35*	-.35*	-.48***	-.38*	-.49***	-.47***

Note. Wt.-Weighted; Stand.- Standardized (See Table 8 for details).
*p < 05; **p < .01; ***p < .001

Table 14

Pre-test Correlations of Project A Psychomotor and Spatial Tests with Different Measures of Effectiveness (MOE)

	Measure of Effectiveness					
	Firing Points (FP) 1, 2 and 3					
	FP3 with Positive Weight		FP3 with Negative Weight		Firing Points 1 and 2	
	Raw Score (A)	Stand. Score (B')	Stand. Score (C)	Wt. Stand. Score (D)	Stand. Score (E)	Wt. Stand. Score (F)
Psychomotor						
Tracking						
One-hand	-.18	-.17	-.15	-.09	-.18	-.15
Two-hand	-.12	-.10	-.05	-.01	-.08	-.06
Cannon Shoot	-.15	-.17	-.15	-.11	-.18	-.19
Target Shoot						
Time to Fire	.01	.01	-.14	-.15	-.08	-.08
Distance	-.19	-.17	-.12	-.04	-.17	-.12
Spatial						
Spatial Reasoning	.14	.15	.35*	.32*	.29*	.26
Object Rotation	.12	.09	.04	-.01	.07	.03
Orientation	.35*	.28	.10	-.03	.22	.15
Maze	.19	.18	.18	.12	.20	.10
Map	.24	.22	.19	.10	.23	.18
Assembling Objects	.16	.16	.15	.09	.18	.14

Note. Wt.-Weighted; Stand.- Standardized (See Table 8 for details).
*p < 05; **p < .01; ***p < .001

Table 15

Post-test Correlations of Some Project A Reaction Time (RT) Tests with Different Measures of Effectiveness (MOE)

	Measure of Effectiveness					
	Firing Points (FP) 1, 2 and 3					
	FP3 with Positive Weight		FP3 with Negative Weight		Firing Points 1 and 2	
RT Tests	Raw Score (A)	Stand. Score (B')	Stand. Score (C)	Wt. Stand. Score (D)	Stand. Score (E)	Wt. Stand. Score (F)
Simple RT Decision Time	-.10	-.09	-.03	.00	-.07	-.06
Choice RT % Correct	.30*	.36**	.31*	.24	.40**	.43**
Short-term Mem. Decision Time	-.21	-.24	-.23	-.17	-.28*	-.27
Number Memory Final Response	-.18	-.24	-.21	-.16	-.27	-.29*

Note. Wt.-Weighted; Stand.- Standardized (See Table 8 for details).
*p < 05; **p < .01; ***p < .001

Table 16

Post-test Correlations of Project A Psychomotor and Spatial Tests with Different Measures of Effectiveness (MOE)

	Measure of Effectiveness					
	Firing Points (FP) 1, 2 and 3					
	FP3 with Positive Weight		FP3 with Negative Weight		Firing Points 1 and 2	
	Raw Score (A)	Stand. Score (B')	Stand. Score (C)	Wt. Stand. Score (D)	Stand. Score (E)	Wt. Stand. Score (F)
Psychomotor						
Tracking						
One-hand	-.20	-.17	-.23	-.17	-.24	-.20
Two-hand	-.23	-.20	-.18	-.11	-.22	-.18
Cannon Shoot	-.24	-.20	.02	.09	-.09	-.09
Target Shoot						
Time to Fire	-.29*	-.19	-.11	-.02	-.21	-.18
Distance	-.19	-.26	-.12	-.08	-.18	-.20
Spatial						
Spatial Reasoning	.12	.17	.29*	.27	.29*	.30*
Object Rotation	.10	-.04	.13	.15	.06	.06
Orientation	.20	.24	.46***	.39**	.43**	.37**
Maze	.26	.32*	.37*	.29*	.41**	.41**
Map	.10	.19	.28	.26	.29	.29*
Assembling Objects	.01	.12	.36**	.37**	.30*	.33*

Note. Wt.= Weighted; Stand.= Standardized (See Table 8 for details)
*p < 05; **p < .01; ***p < .001

Composites A and B' presume the three firing points to be positively or not related; while Composites C and D presume Firing Points 1 and 3 to be negatively related. The reader is reminded that Firing Point 1 and Firing Point 3 are not negatively related at pretest, and that the Orientation test correlates positively with both Firing Points 1 and 3 at pre-test. Table 14 shows that the Orientation Test has higher pretest correlations with MOE Composites A and B' than with MOE Composites C and D, thus, confirming the statement that the Orientation Test correlates with the MOE composite that best reflects the relationships among a performance session's firing points.

The obverse case is found for the Spatial Reasoning Test. The Spatial Reasoning Test's validity coefficients provide an example of how a test's negative correlation with Firing Point 3's MOE and the assignment of a negative weight to Firing Point 3 combine to increase a test's validity coefficient. The Spatial Reasoning Test, which negatively correlates with the MOE for Firing Point 3 at pre-test (Table 8), has higher pre-test correlations with MOE composites C and D (which presume negative correlations among firing points) than with MOE composites A and B (which presume positive correlations among firing points)(Table 14). Finally, the Choice RT Percent Correct measure has positive correlations with the MOE for each firing point at pre-test (Table 9), therefore, resulting in the test's having higher correlations with MOE composites A, B', E and F and lower correlations with composites C and D at pre-test (Table 14).

An example of the effect of weighting each firing point by encounter probability rather than giving each firing point an equal weight is seen for the Number Memory's Final Response time measure. At pre-test, this measure correlates significantly (and in the expected direction) with the MOEs for Firing Points 1 and 2, but not with Firing Point 3 (Table 9). Consequently, giving Firing Point 3 a weight equal to the combined weights of Firing Points 1 and 2 (e.g., Composite D) results in a lower correlation at pre-test than when correlating Number Memory's Final Response time measure with an MOE Composite that gives each firing point an equal weight (e.g., Composite C). (See Table 13).

This part of the Results Section dealt with operationalizing MOE Composites. The basic MOE model was articulated by O'Keefe and Guerrier (1988) and is expanded upon here. Expansion of the model included (a) identifying qualitatively different stimulus conditions, (b) computing an MOE for each condition, (c) identifying the pattern of consistency of individual differences across the conditions, and (d) operationalizing MOE composites based on the pattern of individual differences as captured by the intercorrelations of the firing points' respective MOEs. This systematic algorithm resulted in higher validities reflecting the sensitivity of Project A tests for predicting consistent individual differences across qualitatively different stimulus conditions. The Discussion Section will present a model of DX164 performance based on the correlations between these Project A tests and DX164 performance.

DISCUSSION

This research has shown that Project A tests correlate with TOW gunnery performance on the DX164 simulator both prior to and after soldiers receive extensive training on the simulator. Certain Project A spatial, tracking, reaction time and mental arithmetic tests predict soldier performance on the DX164. These results are all the more impressive, given that the sample studied, although comprised of TOW gunners, was heterogeneous in terms of TOW gunnery experience. One could have expected that differences in experience would interfere with testing for a possible relationship between an ability and TOW gunnery performance. However, the presence of significant correlations between the Project A tests and TOW gunnery performance supports the view that one can employ Project A tests to pick the better TOW gunners, without necessarily considering the TOW gunner's on-the-job history. This Section will employ models of psychomotor performance that will highlight the relationship between psychomotor performance and specific abilities and between psychomotor performance and practice. The models will be employed to offer support to the view that the measurement of abilities allows one to determine different levels of psychomotor competence. It will be suggested that understanding the effects that practice and ability have on psychomotor performance can provide important clues as to what is learned when learning to perform a psychomotor task, such as TOW gunnery target acquisition and tracking, in each of the stimulus conditions captured by the three firing points. Mention will also be made of how such an integrative approach to understanding performance can be used in other research projects.

As just mentioned, two important experimental manipulations in the DX164 data are the field testing of the soldiers at different firing points and the exposing of the soldiers to practice sessions between pre-test and post-test performance sessions. The firing points captured qualitatively different stimulus conditions, resulting in group differences in performance. The intervening practice sessions improved performance in all three firing points.

The Project A tests did not all correlate similarly with DX164 performance. For example, some tests correlated with performance at both pre-training and post-training, while other tests correlated with performance at only one of the performance sessions.

This section will attempt to interpret the pattern of correlations in the context of the effects due to practice and firing point. Models of psychomotor performance will provide the framework for interpreting the pattern of correlations. The intent is to incorporate the experimental design of this project (see Figure 1) and characteristics of the TOW gunnery task into the data interpretation. The section will reflect the following outline:

1. Describe models of psychomotor performance that incorporate dynamics due to practice;

2. Describe a model of learning that incorporates relationships of psychomotor performance with ability measures;

3. Employ Project A tests to provide clues of the skills required for TOW gunnery performance;

4. Incorporate the psychomotor and learning models in 1 and 2 to provide a framework for 3;

5. Suggest a model of TOW gunnery performance based on steps 1-4;

6. Suggest possible research strategies to test aspects of the model.

In general, the Project A tests that correlate with TOW gunnery performance will provide clues as to the skills required for the TOW gunnery task. The tests will be discussed in terms of (a) those tests that correlate with performance at pre-training and post-training, (b) those tests that correlate with performance only at post-training and (c) those tests that correlate with performance only at pre-training. These discussions are presented for each firing point because the performance data provide strong evidence that the firing points captured qualitatively different stimulus conditions.

Automaticity Models and Predictors of TOW Gunnery Performance. The TOW gunnery task has been primarily described in terms of being a psychomotor task (Cartner, et al., 1985). Psychomotor tasks have historically been studied in the experimental literature to determine the effects of practice on performance (Zeaman & Kaufman, 1955). Automaticity models, which incorporate both the traditional, earlier literature of practice effects, as well as some of the current ideas in cognitive psychology, have recently been used to explain performance in psychomotor tasks (Ackerman, 1987; Logan, 1985; Marteniuk, 1976).

Automaticity models are relevant for explaining the results of the present project because (a) they describe mechanisms involved in relatively less practiced versus more practiced behavior, and the transition from less practiced to more practiced behavior (Marteniuk, 1976); (b) they describe strategies for data exploration and experimental manipulation that directly test for characteristics related to differences in behavior due to practice (Logan, 1985); and (c) most importantly with regard to this project, they describe expected relationships between psychometric tests and performance tasks at different stages of practice on the performance tasks (Ackerman, 1987).

Ackerman (1987) provides a model that allows one to determine when psychometric measures are expected to predict performance prior to training versus after training. According to the model, general ability measures, such as intelligence tests correlate to performance prior to training; but as skills training continues, a distinction between performance requiring automatic versus controlled information processing emerges. Those tasks that because of practice are eliciting automatic processing (i.e., require minimal effort), would correlate with tests that tap skills and processes that relate to well-practiced behavior. He suggests psychomotor and reaction time tests as examples of tests relating to (or reflecting) automatic processing after extended practice.

Controlled processing occurs for those task components that do <u>not</u> elicit consistent sequences of information processing components. Controlled processing requires more effort on the part of subjects than automatic processing. Ackerman states that general ability measures (e.g., intelligence tests) and content relevant abilities (i.e., those requiring knowledge of the task) predict controlled processing behavior that is based on extensive practice.

Marteniuk (1976) identifies some of the characteristics in psychomotor tasks that elicit differences in automatic and controlled processing. He hypothesizes a motor schema that is responsible for flexible and adaptive behavior. The schema is based on a store of organized and integrated information that is developed through experience and through the simultaneous occurrence of information in the sensory systems concerned with motor performance.

The visual and kinesthetic systems are two primary sources of information for which Marteniuk cites studies to argue that a system has a memory and transfers information from one system to another (see Chapter 7 in his text). Extended practice results in these systems becoming organized and integrated to allow for their functioning together. Closed and open skills are two types of psychomotor skills which Marteniuk hypothesizes employ, what he describes as, a motor schema.

For a closed skill, the motor schema produces similar movements repeatedly, while for an open skill, the motor schema must be capable of generating many variations of the movement (Marteniuk, 1976). He cites bowling as an example of a closed skill and tennis as an example of an open skill. He acknowledges that no situation is totally closed or open, and stresses that regardless of the motor task, there is a cognitive phase whereby a person employs his/her schema for performing the task.

Marteniuk's model suggests that a person employs general principles that identify the task parameters and integrate the task skills. Each skill may be a highly specific skill that most likely does <u>not</u> correlate with another skill. He suggests that a person performing a psychomotor task can better integrate the task's skills by understanding underlying principles that help integrate the skills. Once having achieved competence in such a cognitive phase, a person practices a closed skill by repetition and an open skill by exposure to different situations.

Psychomotor tasks, according to both Ackerman and Marteniuk, contain a cognitive characteristic for both visual-type and motor-type tasks. Ackerman suggests that the cognitive characteristic remains for tasks requiring controlled processing that is based on extended practice. Marteniuk suggests that the cognitive characteristic is dominant for tasks requiring employment of general principles for becoming competent in an open skill, even after a great deal of practice.

Logan (1985) makes a distinction between automaticity and skill. He suggests that automaticity refers to more specific properties of performance than does skill, but that automaticity is an important component of skill. Skilled performers, according to Logan, have more metacognitive and declarative knowledge than unskilled performers. Metacognitive knowledge includes knowledge of one's capabilities and strategic options, and declarative knowledge includes knowledge of names and other characteristics regarding an area of specialty that may <u>not</u> necessarily be relevant to the specific skill associated with that specialty. The declarative knowledge reflects a "general sense" of knowing an area. These ideas of metacognitive and declarative knowledge, which help define and articulate an expert's area of specialty, appear similar to Marteniuk's ideas of: (a) schema; (b) the role of the cognitive component in learning and performing motor tasks; and (c) the distinction between tasks requiring specific skills versus tasks incorporating an overall knowledge as to how to integrate the task's specific skills.

Logan cites three general paradigms that affect automaticity and skill. He suggests that systematic experimentation by use of these paradigms may help elucidate the characteristics and associated parameters of automaticity and skill when studying learned skills for performing a particular task. The three paradigms are: (a) observation of the co-occurrence of properties, (b) observation of the performance levels of multiple resources and (c) observation of control processes.

Observation of the co-occurrence of properties deals, according to Logan, deals with the idea that for automaticity to occur, a number of components of a task are changing to allow for all the components to be rehearsed and become internally consistent with each other, or as Marteniuk would state, well-integrated. Logan suggests to test co-occurrence by determining whether all the components change in the direction of increasing automaticity. An increase in speed, for example, at the cost of having two components of the task that need to be integrated, interferring with each other, would suggest, according to Logan, a lack of automaticity.

Observation of multiple resources refers to a reduction in one's use of a resource with a concomitant increase in utilizing another resource. Automatization may involve either a general reduction in the use of an executive attentional resource to keep track or integrate different components of the task, or it may also involve a shift in pattern from one resource to another. An example of the latter would be a typist who changes from using visual cues to a typist who uses kinesthetic cues after having extensive practice. A decreased executive attentional resource, or a narrowing toward a specific resource, would, according to Logan, imply a narrow generalization gradient for the trained behavior. Similarly, for Marteniuk's open skill model, reduction of executive attentional efforts would imply skilled performance for more limited situations than when executive attentional efforts are present.

Observation of control processes refers to the interaction between automaticity and control processes. For example, Stroop interference is said to occur because an unattended-to-dimension (e.g., color) may interfere with a dimension that one is using to make a decision (e.g., letters spelling a color). Logan points out that Stroop interference does not necessarily imply that an underlying process (e.g., unattended-to-dimension) is out of control; rather, Stroop interference may only suggest that an automatic process can interfere with performance. The presence of controls, he stresses, can produce interference as well. The point, here, is that automatic processes are <u>not</u> exclusive of controls, but rather they can still be overseen by controls. He cites expert performance as being automatic and, yet, reflecting the presence of controls.

The next section employs the automaticity models and paradigms just described to provide a framework for explaining the significant correlations between the Project A tests and TOW gunnery performance. The strategy is to compare the Project A/TOW gunnery correlations at pre-training versus post-training for each firing point. Where a significant correlation is found, an inference is made that there is a specific or general skill within the Project A test and the stimulus conditions captured by a particular firing point, at a particular practice level (pre-training versus post-training).

The intent is <u>not</u> to state that the correlation between a Project A test and TOW gunnery performance means that a specific skill has been fully identified and articulated for a particular firing point, at a particular practice level. Rather, the intent is to interpret the correlation as an indication of (a) common characteristic(s) between an ability and a specific TOW gunnery skill. Follow-up research can determine, perhaps, based on the interpretations to be presented, the specific aspect(s) of the TOW gunnery task that account(s) for differences in performance among the soldiers and/or that soldiers as a group find difficult.

Firing Point 1. Firing Point 1, in which soldiers wore MOPP IV gear, appears to reflect a transition from an uncrystallized, general strategy (or strategies) related to a number of abilities at pre-training, to a more crystallized, focused, cognitive phase related to more specific abilities at post-training. This appears to be reflected in a number of tests correlating with performance only at pre-training, while specific tests maintained (or increased) their correlations with performance at post-training. For example, the Orientation Test, which had a moderately large correlation with performance at pre-training, increased its correlation with performance at post-training.

The increased correlation of the Orientation Test from pre-training to post-training, with its correlating with performance at both of these sessions, suggests that this test is capturing an important aspect of the TOW gunner's task. These correlations suggest that the TOW gunner's task requires that the soldier interact with a moving target by having a mental image of turning the missile toward the target, and/or mentally maintaining the missile with regard to the target, despite the target's movement in a set direction.

The increase of the correlation between the Orientation Test and performance at post-training as compared to pre-training may be due to individual differences in the emergence of an executive or metacognitive strategy (Logan, 1985), or a more organized and integrated strategy (Marteniuk, 1976) in following the target. One may question whether following the target may become an automatic process. Specifically, soldiers were given extensive practice between performance sessions, but they did not wear MOPP IV gear during those sessions. One may ask whether the correlation between TOW gunnery performance and the Orientation Test (as well as the correlations of performance with the other Project A tests to be discussed shortly) would remain as high or decrease; perhaps, because performance would no longer be based on an investment in effort of a possible executive process. Instead, performance could be based on, perhaps, more specific, less demanding skills which emerge when wearing MOPP IV gear during practice (cf., Ackerman, 1987; Logan, 1985). Regardless of the question, one obtains a "diagnostic sense" by (a) observing which abilities account for performance, and (b) by incorporating those correlations into a framework of psychomotor learning that allows one to model possible underlying processes involved in TOW gunnery performance.

For example, one may further ask, "What characteristics of MOPP IV gear - e.g., mask design, or disoriented feeling, or increased anxiety - account for the effect to which the Orientation Test is sensitive?" Does wearing a MOPP IV mask make it difficult to mentally turn a missile toward the target? Would this possible difficulty to turn the missile toward the target make maintaining the relative position of the missile to the target more difficult? Does the mask result in a more limited and more of an "off-center" view while one is looking into an eyepiece to track the missile?

Similarly, the One-handed and Two-handed Tracking tests, which correlated with TOW gunnery performance at pre-training and post-training for Firing Point 1, reflect an ability of interacting with a moving target, as well. However, these tracking tests may also be sensitive to other aspects of the TOW gunner's task at Firing Point 1, such as reduced kinesthetic feedback because of the gloves worn with MOPP IV gear, and the possibly concomitant greater demand to integrate visual and kinesthetic information. Marteniuk (1976), again, suggests that the integration of these two sources of information is important for successful psychomotor performance, and it is quite possible that the need to integrate visual and kinesthetic information becomes more pronounced while wearing MOPP IV gear.

In contrast, both the Map Test and the Number Operation Test's Final Response dependent measure do <u>not</u> predict Firing Point 1 performance at post-training, despite their relatively large correlations at pre-training. Considering what these tests measure in the context of the automaticity models previously described may explain this decline in the correlations.

The Map Test requires that one consider map coordinates of different landmarks and decide the direction of travel between the two landmarks. One may suggest that since post-training was designed to be an exact replication of pre-training, soldiers performing the DX164 task at post-training quickly identified the location of the target and/or recognized its associated direction of travel. This recognition of location and/or travel direction would preclude the soldier's having to translate the location and direction of travel coordinate information given to him by the tester so that the soldier find and follow the target. In short, the soldier would no longer be translating coordinate information into visual scanning behavior to search for a target along a highly defined route. This inferencing component of the task may also explain the decline in the correlation between the Spatial Reasoning Test and performance from pre-training to post-training at Firing Point 1. Concomitantly, the increase in the correlation of the Maze Test and performance at post-training (versus pre-training) at Firing Point 1 may be reflecting the soldier's scanning for the target <u>without</u> the requirement for determining the target's location and direction of travel.

An issue being raised is, "Does this pattern in the reduction in the correlations for Map And Spatial Reasoning tests, and the increase in the correlation for Maze reflect an improvement in a "general executive process" involved in TOW gunnery, or does this pattern reflect improvement due to sharpening of "specific skills" that are related to performance when one exactly replicates testing conditions?"

One can test these alternative hypotheses by incorporating Ackerman's model with Logan's generalization gradient test for automaticity. For example, one can replicate this project , but include trials at post-training that are <u>not</u> replications of the pre-training trials. If the Map Test correlates more with the post-training trials that are <u>not</u> replications than with the post-training trials that are replications, one can argue that the soldiers were (a) trained for competency for the specific stimulus conditions tested at pre-training; but (b) did not generalize the skills they learned to other stimulus conditions. If the Maze/performance correlations show an opposite pattern, (i.e., lower correlations at post-training for the not previously presented trials than for the previously presented trials), one could state that the Maze Test relates only to TOW gunnery where there is prior knowledge of the direction of movement of the target. If Maze performance, however, correlates with post-training trials that were not previously presented as well as with the post-training trials that were presented, one can argue that Maze performance relates to a TOW gunnery skill reflecting practiced performance, and that this relationship is not restricted to previously presented stimulus conditions. Such a replication study may have implications regarding selection of TOW gunners as well as understanding how different underlying processes and stimulus conditions interact with each other.

The Number Memory Test's Final Response dependent measure, one may argue, requires that the subject focus and update arithmetic information in a brief test requiring mental effort. The decline in the correlation between this measure and TOW gunnery performance at Firing Point 1 post-training versus its high correlation with performance at pre-training may be explained by Ackerman's model.

Specifically, the TOW gunnery task at post-training may no longer elicit a mental effort characteristic of the Final Response measure because with practice, all the soldiers increased their allotted mental effort to maintain sufficient resources to focus and continually update information. One may employ a similar experimental strategy as suggested for the Map Test to test this hypothesis. For example, inclusion of novel situations at post-training may require increased mental effort to update information, with the prediction that the Final Response measure correlate more with these novel situations than with the replicated situations. As stated above, the pattern of correlations may suggest underlying processes involved in TOW gunnery performance and in the dynamics within practice that result in improved performance. Identification of the specific stimuli at Firing Point 1 that affect performance would also explain the correlations observed at this firing point.

Firing Point 2. Automaticity appears to have been achieved in Firing Point 2 post-training, as seen by the extremely high accuracy rate (98%) and fast acquisition times when there was a hit (5.4 secs.). This firing point had the shortest ranges (averaging 1114M) and had the least visual impediments. Soldiers did not wear MOPP IV gear as in Firing Point 1, nor were there obstacles, such as trees between the soldiers and the target as in Firing Point 3.

The Choice Reaction Time Test appears to be sensitive to the relative ease of this firing point. The test's percent correct measure correlates with performance at pre-training and post-training.

The Assembling Objects and Maze tests emerge as predictors at post-training. This pattern for the Maze Test appears consistent with the hypothesis previously presented to explain the test's correlation with performance at Firing Point 1, (i.e., a scanning component appears to emerge as a specific skill when there is extended practice). The Assembling Objects Test had been hypothesized to be sensitive to the ability of quickly detecting a relevant feature from a background (Czarnolewski, 1987 a,b). The appearance of a significant correlation at post-training for Firing Point 2 appears to confirm the hypothesis that Assembling Objects relate to situations requiring detection. The stress in skilled performance at Firing Point 2, appears to be on detection, while at Firing Point 1 appears to be on reorienting.

Firing Point 3. Firing Point 3 appears to be the atypical firing point in a number of ways. First, it is the only firing point containing negative correlations between pre-training and post-training (see Tables 2 and 12). Second, few tests predict performance for this firing point. Third, whatever correlations there are with performance, they elicit an unexpected pattern - the spatial tests correlate negatively with performance at post-training only at Firing Point 3, with the Assembling Objects Test having a significantly negative correlation with percent hits, $r = -.29$, $p < .05$.

Firing Point 3's Engagement 3 appeared to elicit the most atypical pattern in the correlations between predictors and performance. Negative correlations between the predictors with hitting the target were found for the GT Composite, $r = -.30$, $p < .05$, and for Assembling Objects, $r = -.29$, $p < .05$, reflecting a pattern whereby the higher soldiers scored on these tests, the less likely they were to hit the target at post-training. However, a Decision Time Measure for the Short-Term Memory Test had an $r = -.36$, $p < .05$, suggesting that the faster one decides the presence versus absence of a critical stimulus, the more likely the soldiers were to hit Firing Point 3 Engagement 3. In contrast, this Decision Time measure had an $r = +.38$, $p < .01$, for Engagement 4, suggesting that the longer the soldiers took to decide the presence versus absence of a critical stimulus, the more likely they were to hit the target at Engagement 4.

Logan's suggestion to consider the interaction between automaticity and control processes, as well as Ackerman's suggestion to identify the specific abilities that correlate with practiced performance may shed some light toward explaining the uniqueness of Firing Point 3, especially at post-training.

Firing Point 3 Engagement 3 contained a number of unique characteristics: short range (1000 M); intervisibility - based judgment (i.e., it contained objects that could potentially interfere with the missile's hitting the target); right-angle movement (i.e., the angle could have reduced the likelihood that the soldier rely on the perceived size of the target as the target approached the soldier, as compared, for example, to a frontal approach).

The intervening treatments between pre- and post-training performance could have had a prominent effect at Firing Point 3 Engagement 3. Of all the three treatments, not one had an engagement requiring the soldier to consider intervisibility effects (J. Guerrier, October, 1988, personal communication). This coupled with the relatively short range (1000M) of Engagement 3 may have elicited an unexpected interaction effect. The hypothesized effect may be described as follows:

Those soldiers with good spatial abilities (i.e., who were good at mentally re-arranging the scene to incorporate or encode the stimuli) may have experienced conflict as to when to fire. In Logan's terms, their automatic process - which deals with mentally identifying relevant features and re-arranging parts of a field to fit those features together - may have emerged as a dominant strategy while they were searching the scene and incorporating intervisibility effects to decide when to fire. This tendency to consider all the information may have conflicted with their trained control processes to fire when detecting the target, with the conflict resulting in their being less likely to hit the target. However, soldiers whose automatic processing was more sensitive to determining the presence versus absence of the target would not be as likely to experience conflict between their automatic tendency and their trained, controlled processing. These latter soldiers would, therefore, be more likely to hit the target.

In contrast, at Firing Point 3 Engagement 4, the correlation (r = +.38, $p < .01$) between Short-Term Memory's Detection Time measure and hitting the moving target provided evidence that the longer decision time for determining the presence versus absence of a relevant stimulus, the more likely the soldiers will be to hit the target. Engagement 4 did not require inter-visibility-based judgment, but rather required the soldier to wait until the target emerged from a frontal positioned, approaching cloud of dust that started 1700M down range. The apparent lack of an intervisibility-based judgment here could have precluded the conflict that is hypothesized to have emerged at Engagement 3.

CONCLUSIONS

This report identified the primary Project A predictors of DX164 performance. The report determined the primary predictors by (a) computing an MOE for each firing point to capture unique characteristics of that firing point and correlating ability measures with each MOE, and (b) computing an MOE Composite by employing an algorithm that was sensitive to consistency in individual differences across stimulus conditions (i.e., firing points), and comparing the correlations of the Project A tests with this MOE Composite versus other MOE Composites.

The dominant Project A predictors at post-training were the Orientation, Maze, and Assembling Objects spatial tests, the One-Handed and Two-Handed psychomotor tracking tests, and the Choice Reaction Time speeded test. One may state that these tests appear to relate to relevant TOW gunnery skills that require the soldier to maintain the missile on the target by mentally coordinating the missile's movement with the target's movement, and by employing psychomotor coordination to maintain the missile's staying on the target. The tests also appear to relate to the ability of quickly detecting targets in the readily discernible, short-range stimulus conditions of Firing Point 2.

The prominent correlations of the Orientation, Maze, One-Handed and Two-Handed tracking tests replicated previous research efforts where these tests were found to predict TOW gunnery performance with the M-70 TOW2 simulator for soldiers graduating AIT. Replication in prediction of performance by these tests is all the more impressive, given the differences in the samples, their training histories and the use of a day sight optical device for 16 of the 18 engagements in the present project versus the use solely of a night sight, infrared optical device in the project analyzed by Grafton, et al.

The present report suggests models of performance to understand the possible underlying dynamics between training and specific abilities that result in successful performance. It is suggested that this approach be considered when determining required abilities for planned systems as is currently being done in the MANPRINT effort (Kaplan, 1985). The present report's results suggest that efforts, such as MANPRINT also consider other relevant variables, such as training, stimulus conditions, and likelihood of encountering those stimulus conditions when matching human abilities to planned systems.

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